

How Do Planets Take Shape?

A newly discovered mechanism helps explain planet formation, stellar winds, and more.

by Whitney Clavin

Caltech researchers have discovered a new mechanism to explain how the act of dust moving through gas leads to clumps of dust, which could explain everything from planet formation to outflows from stars, to the settling of volcanic ash. While dust clumps were already known to play a role in seeding new planets and many other systems in space and on Earth, how the clumps formed was unknown until now.

Phil Hopkins, Caltech professor of theoretical astrophysics, who carried out this work with Jonathan (Jono) Squire, a former postdoctoral fellow at Caltech, says that it was previously assumed that dust was stable in gas, meaning the dust grains would ride along with the gas without much happening, or they would settle out of the gas if the particles were big enough, as is the case with soot from a fire.

“What Jono and I discovered is that dust and gas trying to move with one another is unstable and causes dust grains to come together,” says Hopkins. “Soon we began to realize that these gas-dust instabilities are at play anywhere in the universe that a force pushes dust through gas, whether the forces are stellar winds, gravity, magnetism, or an electrical field.” The team’s simulations show material swirling together, with clumps of dust growing bigger and bigger.

Perhaps the most notable implications for the newfound Hopkins-Squire instabilities are for the study of burgeoning planets. Planets take shape within dusty, rotating “protoplanetary” disks of gas and dust around young stars. In these disks, the dust coalesces to form bigger and bigger pebbles and boulders, then mountain-size chunks, and eventually full-grown planets.

At some point during this process, when the pieces of rock are big enough, about 1,000 kilometers in diameter, gravity takes over and smooshes the mountainous rocks into a round planet. The big mystery lies in what happens before gravity takes effect, that is, what is causing the dust particles, pebbles, and boulders to come together? Researchers once thought they might stick together in the same way dust bunnies accumulate under your bed, but there are problems with that theory.

“If you throw two pebbles together, they don’t stick. They just bounce off each other,” says Hopkins (pictured at right). “For sizes in between a millimeter and hundreds of kilometers, the grains don’t stick. This is one of the biggest problems in modeling planet formation.”

In the Hopkins-Squire instability model, which builds on previous models of dust-gas interactions, the formation of planetary dust clumps would begin with tiny dust grains moving through the gas orbiting in a protoplanetary disk. Gas would curl around a grain like river water around a boulder; the same thing would happen with another grain of dust nearby. These two gas flows might then interact. If there are many dust grains in relatively close proximity to one another, which is the case in planet formation, the net effect of the many resulting gas flows would be to channel the dust together into clumps.

“In our new theory, this sticking through clumping can occur for a much wider range of grain sizes than previously thought, allowing smaller grains to participate in the process and rapidly grow in size,” says Squire.

These instabilities may also be important in completely different situations here on Earth. For instance, volcanic ash or raindrops interact with our atmosphere in exactly the same way that astrophysical dust interacts with its surrounding gas.

“It’s very interesting to explore how these instabilities could operate in all these different scenarios,” says Squire. “We’re looking forward to understanding completely different instabilities in other areas of physics and applied mathematics and, hopefully, to finding other entirely new and interesting systems where this occurs.”

This research was funded by NASA and the National Science Foundation.



To watch a video about the Hopkins-Squire instability model, go to magazine.caltech.edu/post/planetshape